# A Micro-Fabricated Segmented Ion Trap For Quantum Computation

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## Motivation

The first proposal for ion-trap quantum computation involved confining a string of ions in a linear Paul trap, using their electronic states as qubit logic levels, and transferring quantum information between ions through their mutual Coulomb interation. In recent years, all the elementary requirements for quantum computation have been demonstrated in such a system. However, manipulating a increasing number of ions in a conventional linear ion trap becomes extremely technologically difficult, and scaling arguments suggest that this scheme is limited to computations on tens of ions.

In 2002, Kielpinski, Monroe and Wineland proposed a "quantum charge-coupled device" architecture which seeks to make ion trap quantum computing scalable

"Interaction" region

"Storage" region

Control electrodes

RF electrodes
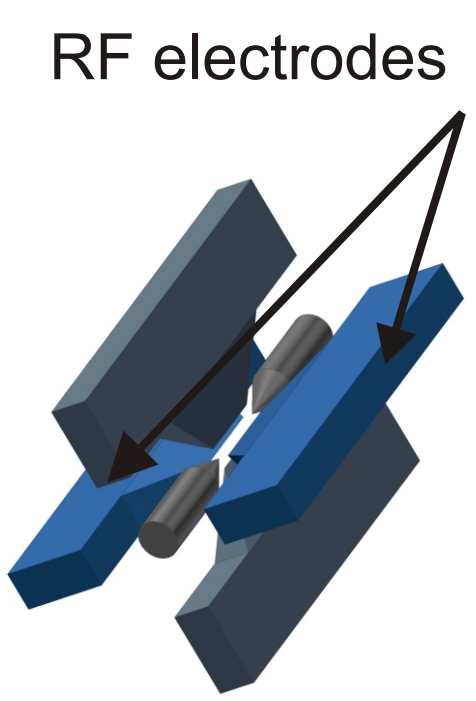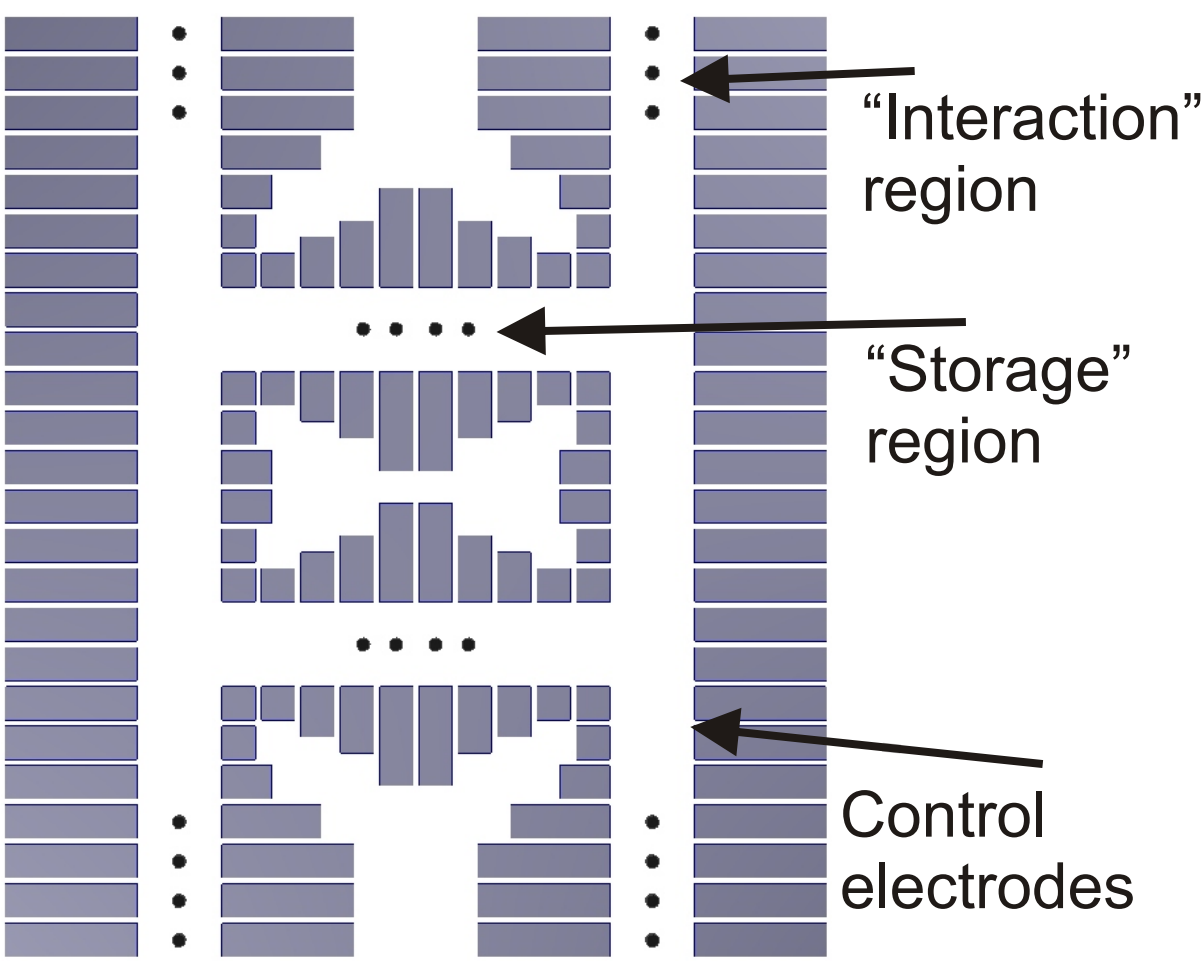
Schematic of a microfabricated segmented ion trap with two layers.

Production using standard microfabrication tecniques offers the possibility of precise and complex geometries.
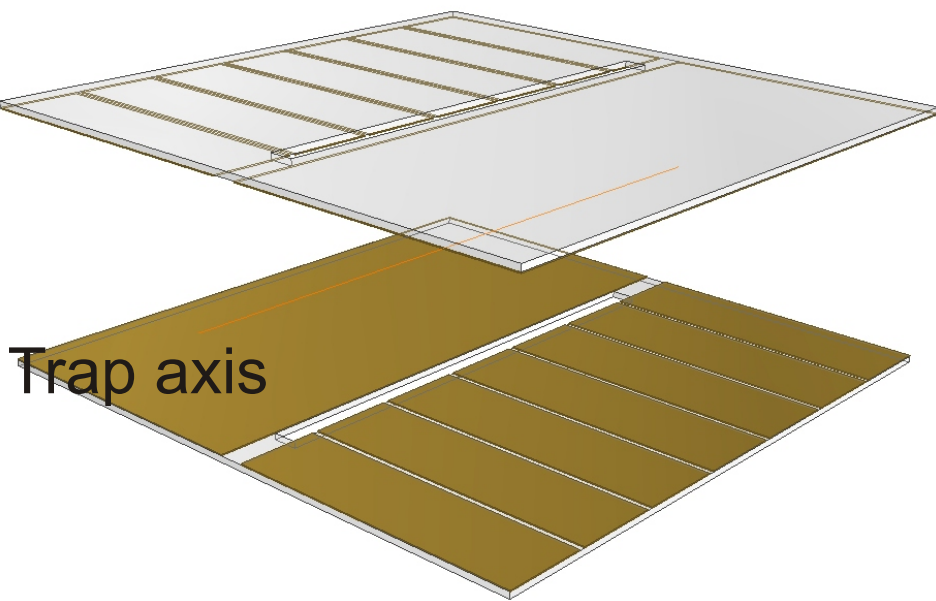
Schematic of a linear Paul trap used for quantum information processing in Innsbruck

Trap axis

## Electrode layouts of first chip traps
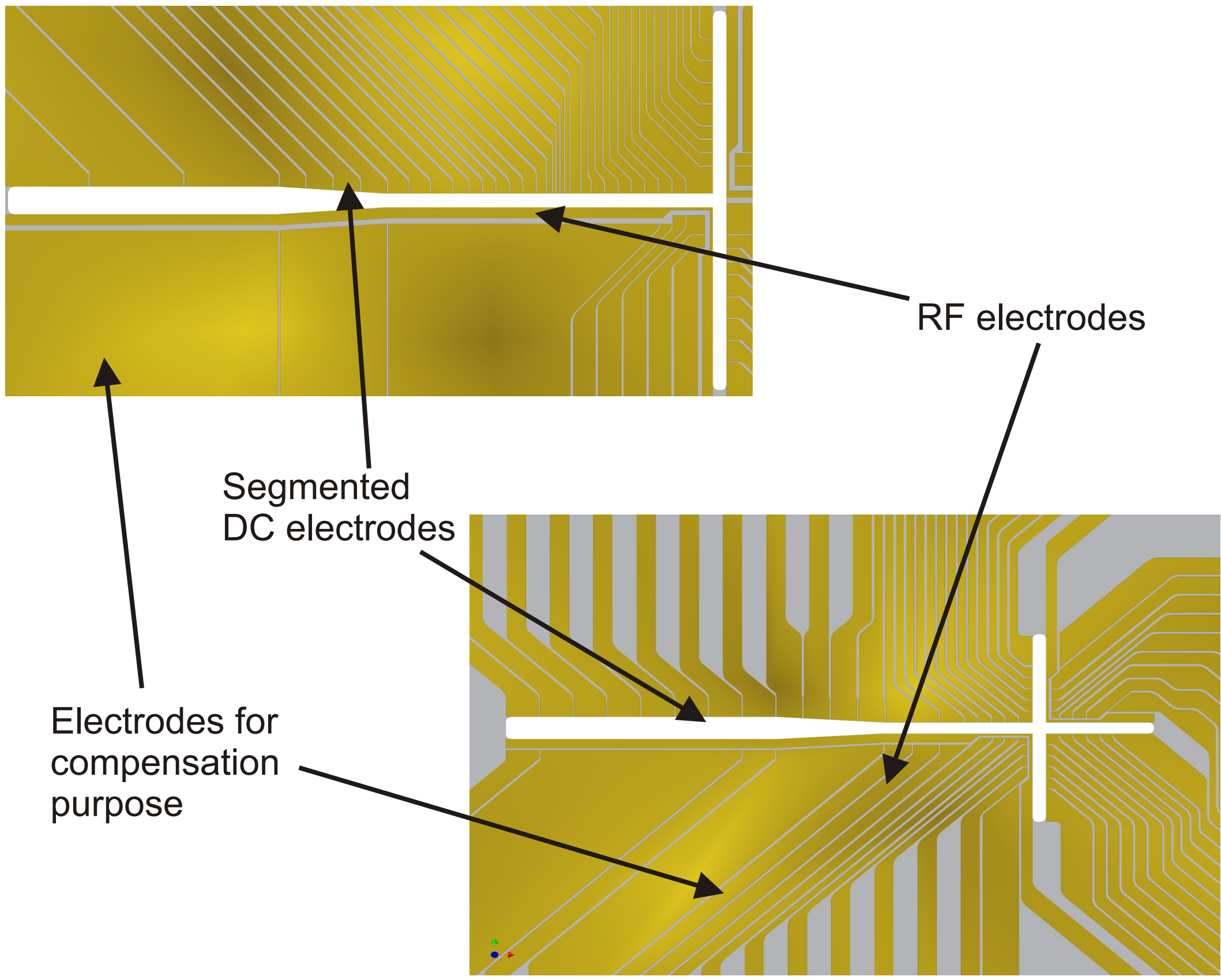
The first designs of the microfabricated traps implement trapping zones of different sizes, zones for splitting the ion-string and X- and T- shaped crossings.

These designs are all based on electrode arrangements in two layers.

RF electrodes

Segmented DC electrodes

Electrodes for compensation purpose

## Simulations with COMSOL Multiphysics

COMSOL Multiphysics is a software package suitable for modelling and simulating many physical problems which can be described with partial differential equations. COMSOL Multiphysics uses the Finite Element Method to numerically solve the relevant physical equations.

From the RF and DC field calculations, the axial and radial trapping potentials can be derived, and the trap can be fully characterised.

We can simulate the potentials created by the segmented electrodes, and can tailor these potentials for optimal movement of the ions in the segmented trap.
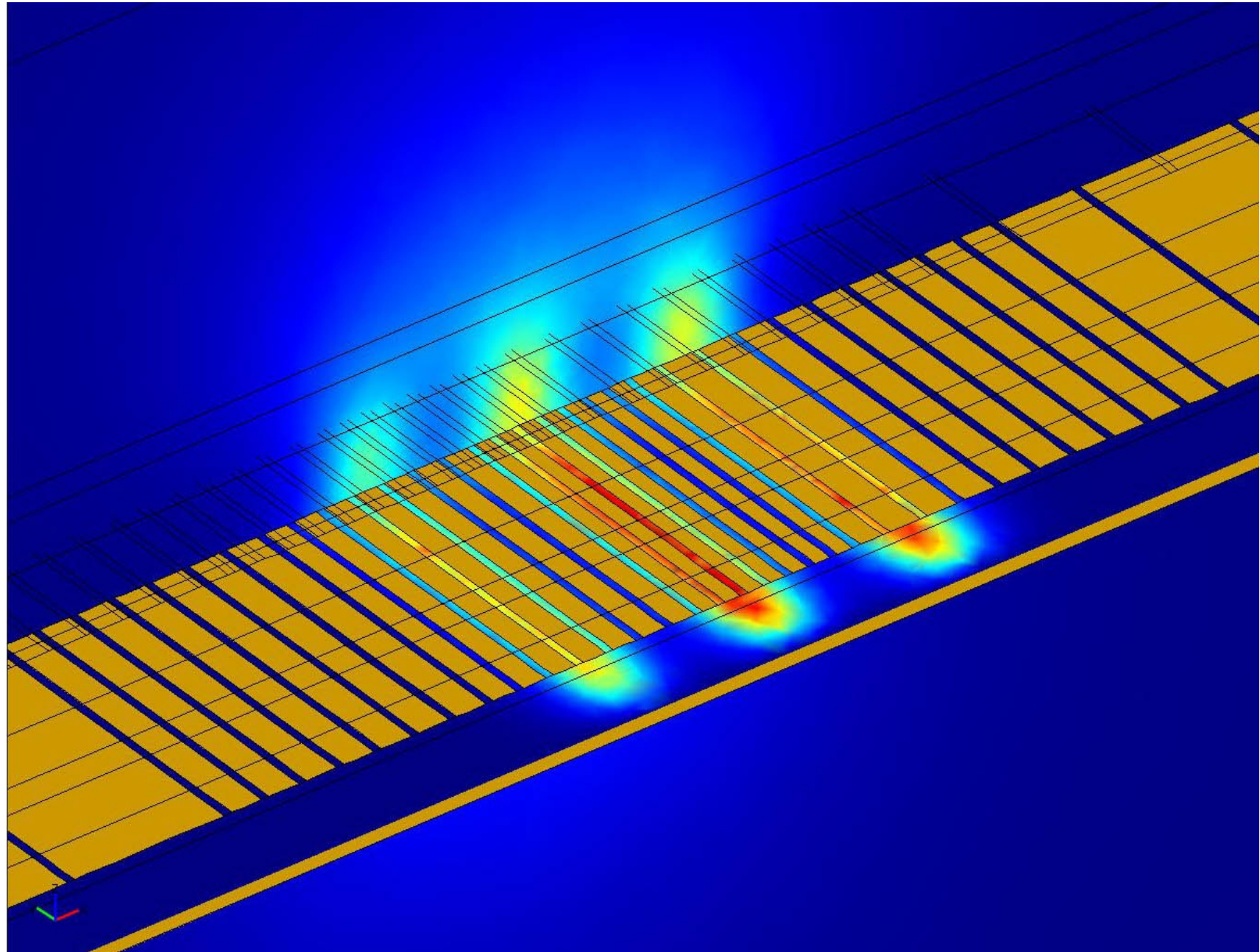
Simulation of DC field in a linear segmented trap geometry. The electrodes, which are 2 micron thick in real life, are modelled as two-dimensional structures embedded in a three-dimensional space. The entire trap geometry can be modelled in a single file. On the left an exemplary simulation to create two potential wells is shown. -one step in the splitting of an ion string.

COMSOL Multiphysics can solve for complex geometries such as this one: 174 boundaries - 80 segmented electrodes, 2 RF electrodes, 2 compensation electrodes, 2 planes, and 82 insulating spaces.

For the loading process the outmost electrodes can be used as "endcaps"

AUSTRIAN GRID

Our collaboration with the Austrian GRID places allows us use of sophisticated computers with large memory resources - crucial for accurate and detailed simulations.

## Trap Fabrication

Fraunhofer Institut Angewandte Optik und Feinmechanik

Trap fabrication is completed in collaboration with the Precision Engineering group at the Fraunhofer Institut für Angewandte Optik und Feinmechanik, Jena, Germany.
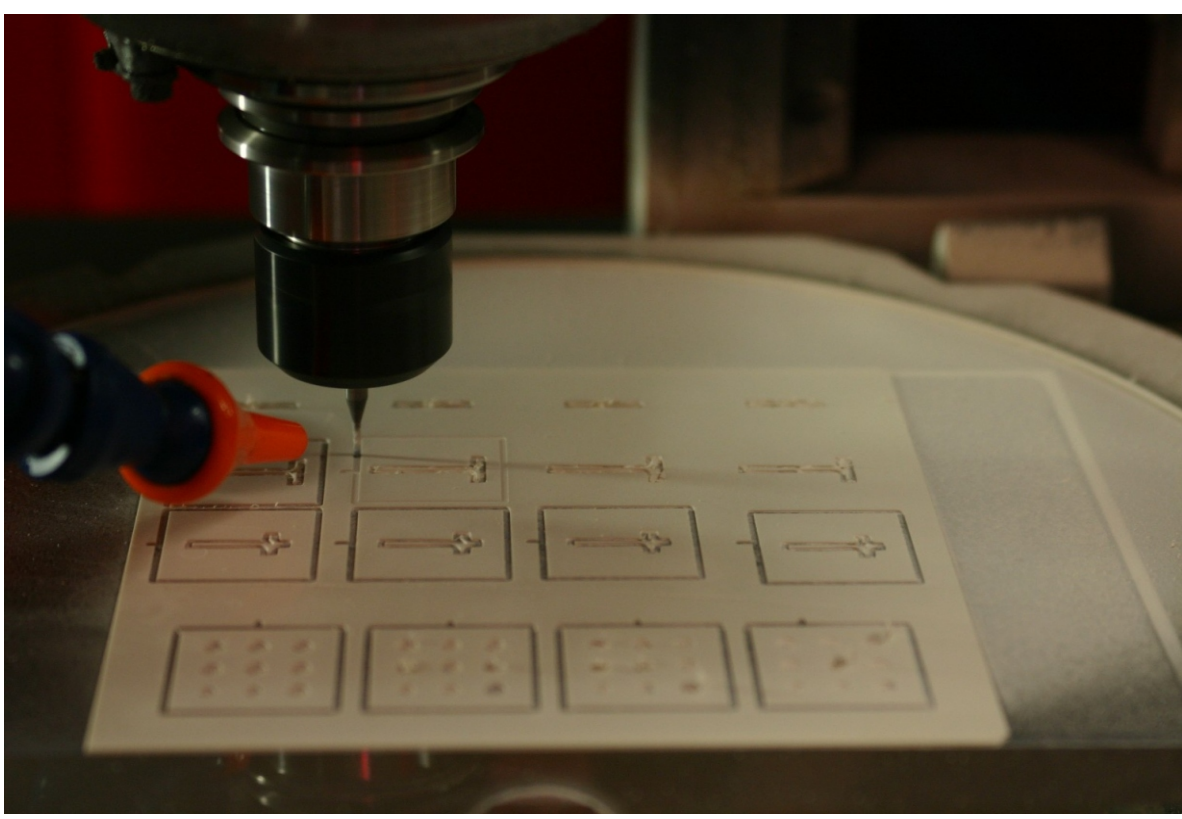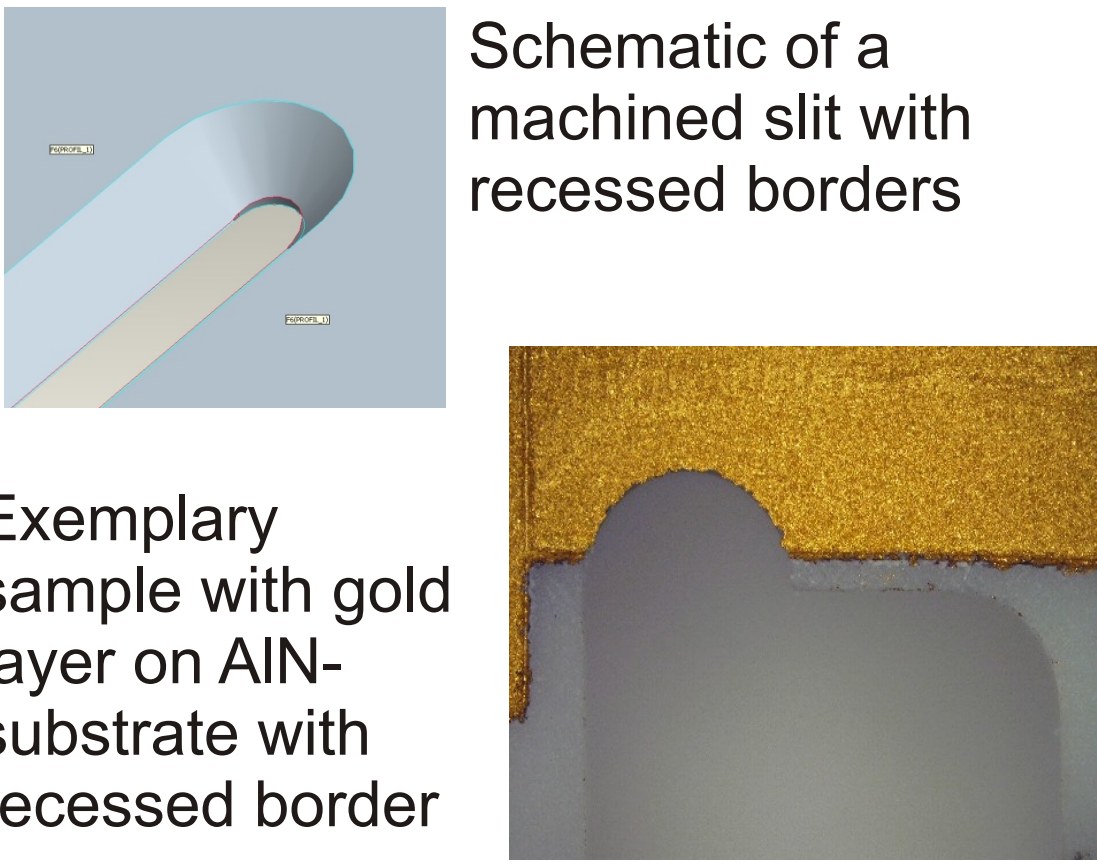
Electrode fabrication: Metalization of substrate material followed by photolithographic etching and ceramic machining.
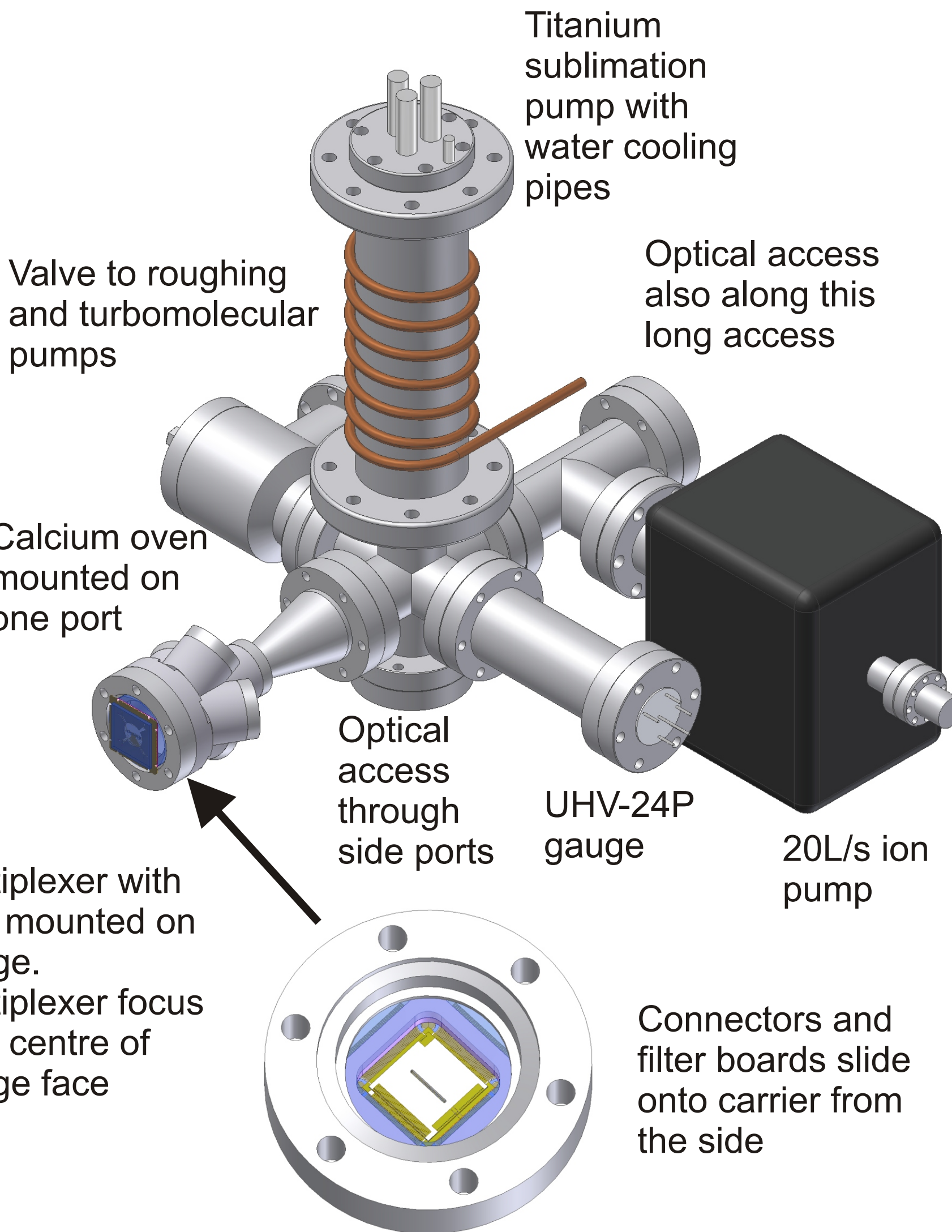
Assembly:Trap layers and spacers are joined with UHV-compatible epoxy (Epotek 353ND) and assembled with a "fineplacer" to 5 micron

Substrate: Shapal wafer (Aluminium Nitride) meeting the following requirements:
- high mechanical strength
- low thermal expansion
- heat resistance
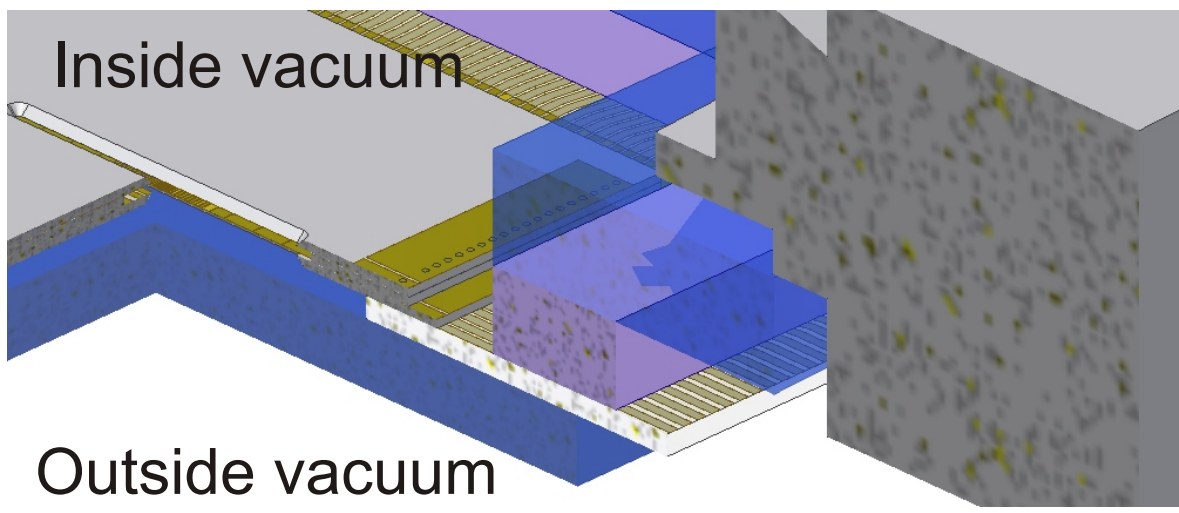- capable for UHV conditions

Electrodes: Titanium (0.1 micron) followed by Gold (2 micron) Precision of the structures is +- 5 micron

Schematic of a machined slit with recessed borders

Exemplary sample with gold layer on AlN-substrate with recessed border

## Vacuum apparatus

Titanium sublimation pump with water cooling pipes

Valve to roughing and turbomolecular pumps

Optical access also along this long access

Calcium oven mounted on one port

Optical access through side ports

UHV-24P gauge

20L/s ion pump

Multiplexer with trap mounted on flange. Multiplexer focus is at centre of flange face

Connectors and filter boards slide onto carrier from the side

## Novel UHV Trap mounting

### Detail of feedthrough

Inside vacuum

Outside vacuum

Electrodes for connection to segments pass under the outer spacer. Connection is made vacuum tight with Epotek 353ND epoxy. KEL USA connectors with attached filter boards simply slide onto the carrier substrate and are automatically aligned.

### Cross-sectional view of trap mounted on flange
(Schematic only - not to scale)

Segmented DC electrodes

Glass window

Carrier substrate

Carrier electrodes

Outer spacer

Viewport glass

Wire bonding connections

Bond pads

Vias

RF electrodes

Inner spacer

Viewport metal flange